TRANSLATION

WIRELESS POWER TRANSMISSION

By

Ming-Tau Hua

FOREIGN TECHNOLOGY DIVISION

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

OHIO

EDITED TRANSLATION

WIRELESS POWER TRANSMISSION

BY: Ming-Tau Hua

English Pages: 8

SOURCE: K'o Hsueh Ta Chung (Chinese), No. 11, 1963, pp. 12-13.

C/0085-063-000-011

PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

WIRELESS POWER TRANSMISSION

Ming-Ta Hua

In the process of transmitting electrical energy by wire some energy is converted into heat and becomes lost. To reduce the heat loss in the transmission of a large quantity of electrical energy, one must increase the diameter of the conducting wire, suspend it on insulators mounted on tall steel towers, and raise the voltage to several hundred thousands or even millions of volts. All these measures greatly increase the capital investment and the costs of maintenance and repair. Scientists, therefore, begin to wonder: is it possible to discard the conducting wire and resort to the radio-electronic method of converting the electrical energy into high-frequency oscillations and transmitting the energy through antennas in the form of radio waves?

As early as thirty years ago, radio transmission had been suggested as a method of delivering energy. At that time, radio waves were first used in broadcasting and communications, and their wavelengths were quite long. Such waves propagate in all directions in space, resulting in a great deal of energy loss. The idea of power transmission, therefore, could not be materialized.

During World War II, radar was invented. It operated on microwaves. The term "microwaves" refers to radio waves with wavelengths below one meter or frequencies greater than 300 megacycles. One of the characteristics of microwaves is that the waves are compressible into narrow beams propagating in a specific direction. It therefore suggests

FTD-TT-64-795/1+2+3+4

the possibility of eliminating a great deal of the energy dissipation resulting from ordinary radio wave propagation in all directions and, consequently, the possibility of transmitting energy by microwaves.

KEY TO THE PROBLEM

Why, then, have we failed until today to transmit electrical energy by radio techniques? The problem lies in the fact that the present electronic tubes available have very low power ratings. To deliver electrical energy by radio techniques requires a high-power high-frequency oscillator for conversion of electrical into radio energy. What, then, constitutes the difficulty in manufacturing this type of oscillator?

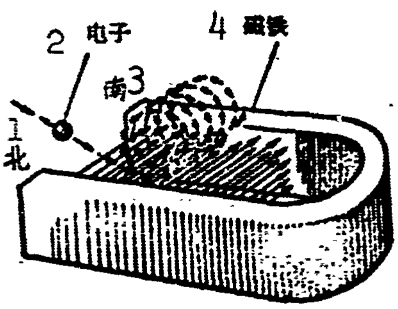

Fig. 1. The magnetic field causes the trajectory of an electron to bend. 1) N; 2) electron; 3) S; 4) magnet.

The principal part of an oscillator is the vacuum tube. Let us now consider the working principles of an ordinary vacuum tube.

The cathode of a vacuum tube emits electrons when it is heated. In a vacuum these electrons flow to the anode at a high speed. Emission of electrons occurs in the form of dense electron clouds. Since all electrons are negatively charged they tend to repel each other and consequently move in a disorderly manner in all directions. When the power of the tube is low the disorderly motion of electrons is not quite as serious. As the power input of the tube increases, the number of electrons emitted increases and the electron clouds become denser. Consequently, the repulsive forces between electrons may increase to such an extent that the directional flow of electrons is completely disrupted. In other words, the number of electrons arriving at the anode is greatly reduced.

In the beginning it was thought that such repulsive forces could

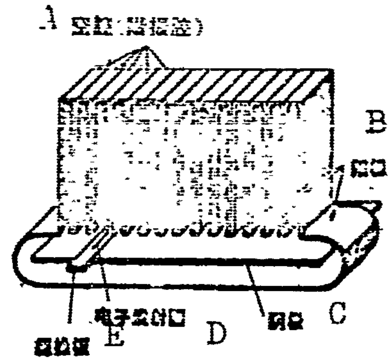

Fig. 2. The magnetron is a type of electron-tube that can produce ultrahigh frequency oscillations. Its anode is a hollow cylinder which has a number of cavities (resonance cavities) and gaps. The cathode is positioned in the center of the hollow cylinder. A) Cavities (resonance cavities); B) anode; C) cathode; D) electron emitter; E) insulating plate.

be successfully eliminated by enlarging the dimensions of the vacuum tubes. But it was soon realized that this was an unrealistic approach. In order to compensate for the effect of inter-electronic repulsive forces, which increase with increasing power, the dimensions of the cube must be increased in proportion to the square of the power. As the power is doubled the increase in the tube dimension must be fourfold. At present, a vacuum tube of several hundred kilowatts power is the size of a steel drum. The tube will be incomparably larger if it is desired to increase the power to several hundred thousand kilowatts.

The problem can be solved if we force the electrons to flow in a magnetic field. If the electrons move in the direction of the magnetic field they will be subjected to the focusing effect of the field and will not diverge in all directions. If the electrons move in a direction normal to the field direction their trajectories will be bent by the field and become spirals about the axis of the magnetic field.

The magnetrons which are now used for production of ultrahigh frequency oscillations are built in compliance with this principle. The major parts of a magnetron include: cathode, anode, high-frquency output terminals, etc.

An electric field is applied between the cathode and the anode of the magnetron. The electrons emitted by the cathode fly to the anode under the influence of the applied field. A magnetic field is applied in the direction of the longitudinal axis of the cylindrical anode. As

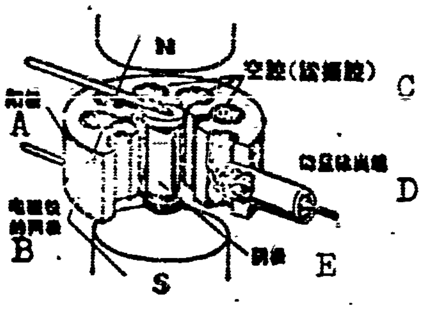

Fig. 3. The planar-type magnetron resembles an ordinary magnetron whose anode has been unfolded into a plane. A) Anode; B) two poles of the electromagnet; C) cavities (resonance cavities); D) output terminal; E) cathode.

the electrons are on their way to the anode their trajectories will be bent under the influence of the magnetic field. If the magnetic field intensity is properly chosen the electrons will sweep by the surface of the anode and cause oscillations in the cavity (resonance cavity) which create alternating electric fields in the vicinity of the gaps. The direction of these fields is such that the moving electrons are accelerated at one moment and decelerated at the next. As the electrons move in a decelerating field they give up their energy. Since the cathode emits electrons continuously and the electrons revolve about the cathode, the cavity will obtain energy continuously and produce high-frequency oscillations of considerable power. Present magnetrons, however, have rather low power output, and their efficiency is also quite low, generally about 70%. It has reported that a new magnetron (amplitude multiplier) has an efficiency reaching 80%. Recently, a new planar-type magnetron has been developed on the same working principle as that of an ordinary magnetron. An efficiency of 90% has been achieved for the new magnetron in laboratories. Furthermore, the function of the new magnetron is reversible. The magnetron not only produces a high-frequency oscillation, but also can convert the high-frequency oscillation into electrical energy. It seems that the planar type magnetron is a promising high-power, high-frequency oscillator.

As far as transmission of microwaves is concerned there are two methods which can be used. One method is the transmission by wave guides; the other is transmission by relay stations.

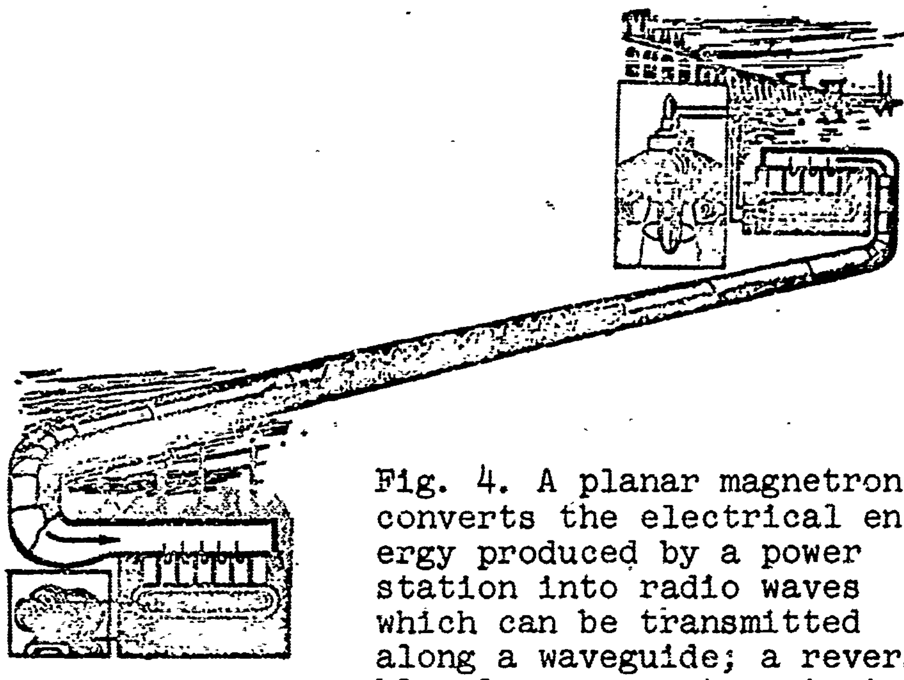

Fig. 4. A planar magnetron converts the electrical energy produced by a power station into radio waves which can be transmitted along a waveguide; a reversible planar magnetron is intalled at the other end of the waveguide to convert the radio waves into electrical energy.

TRANSMISSION BY ELECTRIC PIPE LINES

Microwave energy can propagate in waveguides (metallic pipes that can propagate radio waves). The situation is analogous to water flowing in the water pipes, and can be readily controlled. The wave guides do not require insulation and can be installed above or under the ground. The direct current produced at power stations can be sent to a planar magnetron connected to one end of the waveguide. The electrical energy is converted into ultrahigh frequency oscillation and is transmitted in the form of radio waves along the waveguide. Furthermore, it can be transmitted from the main line to branch lines. The waveguides have a large carrying capacity; a million kilowatts of electrical energy can be transmitted by one square meter of cross section.

Radio waves transmitted by waveguides can be sent directly to metallurgical furnaces to melt and refine metals, or to mining sites to melt the rock formations and extract minerals such as sulfur.

When the electricity is needed the radio waves can be converted

into direct current by connecting a planar reversible magnetron at the output end of the waveguide. The current can then be sent to industrial enterprises and other users by conducting wires.

TRANSMISSION BY RELAY STATIONS

We can also use radio installations to convert the a.c. power produced by hydroelectric or thermoelectric stations into ultrahigh frequency oscillations and then transmit it in the form of directed beams of radio waves by means of paraboloidal antennas. A microwave receiving station can be established at another town to convert the microwaves received into ordinary d.c. or a.c. power, which is then delivered to users.

It should be pointed out that the propagation of microwaves in the atmosphere will be affected by weather conditions. It has been proven empirically that microwaves with frequencies ranging from 10 to 15 thousand megacycles have the smallest attenuation under normal weather conditions. In light rain the attenuation is approximately 0.03 decibel every kilometer; in heavy rain the attenuation is as great as 0.3 decibel (equivalent to a 0.07% loss in efficiency). Furthermore, microwaves propagate in a straight line. If two stations are very far apart the antennas must be installed at a great height. At a distance of 40 kilometers, for instance, the antenna will be about 30 meters high. At a distance of 80 kilometers the antenna will be over 100 meters. This is, of course, uneconomical, and the problem can be solved by the relay method, which consists of establishing a number of intermediate relay stations to form a relay line. The microwave power is transmitted from point A to a relay station at point B. The relay station at B consumes a part of the electrical energy and transmits the rest by antenna to point C. The process of reception and transmission is repeated station after station so that the energy can be de-

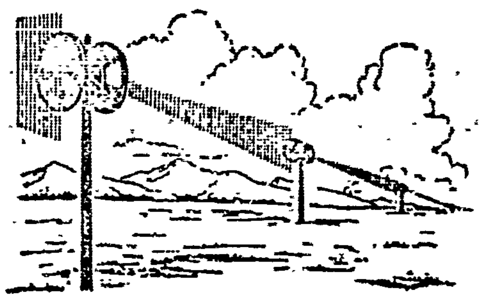

Fig. 5. Transmission of electrical energy by relay stations.

livered over a great distance. This is really what we mean by wireless power transmission.

MICROWAVE TRAINS AND TRACTORS

Power transmission by relay lines can be used to realize the concept of microwave railway trains. Ordinary trains are powered by steam-driven locomotives or internal combustion engines which consume coal or gasline and are quite uneconomical. The use of electric locomotives would require costly installation of many electric poles along the railroad as well as a large quantity of wire. The microwave trains of the future will use the electrical energy received by the microwave receiver to operate the electric motor. A number of microwave relay stations will be established at prescribed intervals along the railroad so that the electrical energy can be transmitted from the main station to the stations along the railroad line. As the locomotive moves, the transmitting antenna of a station will be aligned with the receiving antenna of the moving locomotive with the aid of automatic control systems. The electrical energy will be delivered to the moving locomotive station after station in this way. At the point of cross-over the locomotive will receive electrical energy simultaneously from two transmitting stations. Two antennas are, therefore, installed on every locomotive.

The microwave tractors of the future can obtain electrical energy by the same method as described above. A microwave relay station can be established in a village. The relay station will have a receiving antenna and a number of transmitting antennas. It receives microwave energy from a large station and then transmits the energy to a number of mobile relay vehicles. The vehicles are themselves driven by the

microwave energy, and transmit the energy from the main station to various tractors. The receiving antenna on a tractor will be aligned automatically with the transmitting antenna on a relay vehicle so that the tractor will receive the energy to operate without interruption. If a group of tractors is transferred from one place, A, to another, B, the relay vehicles can be transferred with them.

The transmission of electrical energy by the radio-electronic method is still in its experimental stage. There are many problems to be solved by engineers and scientists. We believe, however, that this method of power transmission will, in the near future, step out of the laboratory and find its application in the electric power industry.

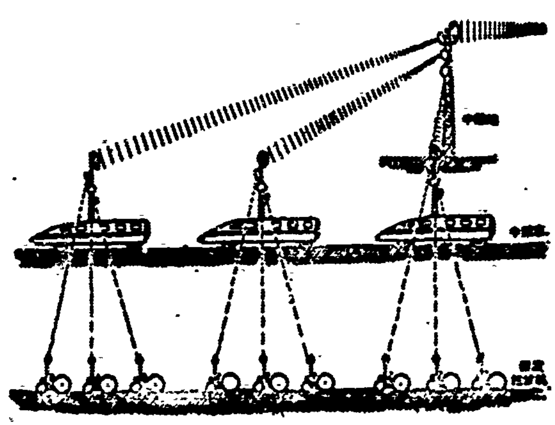

Fig. 6. Microwave tractors.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE	Nr. Copies	MAJOR AIR COMMANDS	Nr. Copies
		DDC	20
		AFSC	
		SCFTC	1
		TDBDP	2
		TDBDP (Mrs. Webb)	1
		TDBTL	5
HEADQUARTERS USAF		TDGS	1
		SSD (SSFAR)	2
		TDEEC	1
ARL (ARB)	1	AEDC (AEY)	1
		AFETR (MTW)	1
		AFWL (WLF)	1
		APGC (PGF)	1
		ASD (ASFS)	2
		ESD (ESY)	1
		RADC (RAY)	1
OTHER AGENCIES			
AEC	2		
ARMY (FSTC)	3		
NAVY	3		
DIA	4		
ATD	2		
CIA	5		
NASA (ATSS-T)	1		
NSA	6		
OAR	1		
OTS	2		
PWS	1		
AFCRL (CRXLR)	1		
SPECTRUM	1		